BRAIN RESEARCH 1557 (2014) 66–73

Available online at www.sciencedirect.com

ScienceDirect

www.elsevier.com/locate/brainres

Research Report

ERP profiles for face and word recognition are based on their status in semantic memory not their stimulus category

Aiqing Nie[a], Michael Griffin[b], Alexander Keinath[b], Matthew Walsh[b,d], Andrea Dittmann[c], Lynne Reder[b,d,*]

[a]Department of Psychology and Behavior Science, Zhejiang University, Hangzhou 310028, China
[b]Psychology Department, Carnegie Mellon University, Pittsburgh, PA 15213, USA
[c]Psychology Department, St. Olaf College, Northfield, MN 55057, USA
[d]Center for the Neural Basis of Cognition, Carnegie Mellon University, Pittsburgh, PA 15213, USA

ARTICLE INFO

Article history:
Accepted 4 February 2014
Available online 12 February 2014

Keywords:
Recognition-memory
Famous
Words
Early old/new effect
Late old/new effect
Faces

ABSTRACT

Previous research has suggested that faces and words are processed and remembered differently as reflected by different ERP patterns for the two types of stimuli. Specifically, face stimuli produced greater late positive deflections for old items in anterior compared to posterior regions, while word stimuli produced greater late positive deflections in posterior compared to anterior regions. Given that words have existing representations in subjects' long-term memories (LTM) and that face stimuli used in prior experiments were of unknown individuals, we conducted an ERP study that crossed face and letter stimuli with the presence or absence of a prior (stable or existing) memory representation. During encoding, subjects judged whether stimuli were known (famous face or real word) or not known (unknown person or pseudo-word). A surprise recognition memory test required subjects to distinguish between stimuli that appeared during the encoding phase and stimuli that did not. ERP results were consistent with previous research when comparing unknown faces and words; however, the late ERP pattern for famous faces was more similar to that for words than for unknown faces. This suggests that the critical ERP difference is mediated by whether there is a prior representation in LTM, and not whether the stimulus involves letters or faces.

Published by Elsevier B.V.

1. Introduction

Dual-process models have been influential in the study of recognition memory. These models propose that recognition depends both on familiarity, a relatively automatic process, and recollection, a more deliberate one (Jacoby, 1991; Yonelinas, 2002; Curran and Hancock, 2007). Consistent with a dual-process model, previous ERP research investigating

*Corresponding author at: Department of Psychology, Carnegie Mellon University, 5000 Forbes Avenue, Pittsburgh, PA 15213, USA. Fax: +1 412 268 2844.
E-mail address: reder@cmu.edu (L. Reder).

http://dx.doi.org/10.1016/j.brainres.2014.02.010
0006-8993 Published by Elsevier B.V.

recognition memory typically describes canonical patterns of waveform differences between recognized (old) and correctly rejected (new) items that parallel the processes of familiarity and recollection. Specifically, the early old/new effect (also called the FN400), a negative component (more negative for new than old items) that appears around 400 ms over the anterior scalp, is thought to reflect familiarity, while the late old/new effect, a positive component (more positive for old than new items) that appears after 500 ms over the posterior scalp, is thought to reflect recollection (e.g., Curran, 1999; Curran and Doyle, 2011; Curran and Hancock, 2007; Diana et al., 2005; Graham and Cabeza, 2001; Paller et al., 2000; Wilding et al., 1995).

However, several recent studies have reported that the spatial and temporal distributions of these old/new effects differ for faces and words (e.g., MacKenzie and Donaldson, 2009; Yick and Wilding, 2008), raising the possibilities that faces are recollected differently from words, or that ERP correlates of memory retrieval for faces and words are material specific. While the early old/new effect for face stimuli has been inconsistently obtained in studies of recognition memory, the effects that have appeared are fairly similar to words. Yovel and Paller (2004), as well as MacKenzie and Donaldson (2007) found no early old/new effect for face stimuli. Curran and Hancock (2007), by contrast, did find an early old/new effect using a very similar paradigm with face stimuli.

In the study by Yick and Wilding (2008), early and late old/new effects were observed for faces and words, but the spatial distribution of these ERP components differed by stimulus type. An early old/new effect appeared over the anterior region for both faces and words. But from 500 to 800 ms, words showed the expected old/new effect with a parietal maximum, while this later old/new effect was maximal over the anterior scalp for face stimuli.

MacKenzie and Donaldson (2009) compared names with faces and found a pattern similar to that of Yick and Wilding. Comparing hits to correct rejections, they found that from 300 to 500 ms, faces and words showed similar early old/new effects. Consistent with Yick and Wilding, from 500 to 700 ms, the old/new effect evoked by faces was maximal over the anterior scalp, while the old/new effect evoked by words was maximal over the posterior scalp.

Taken together, these results suggest that the spatial distributions of the early (~400 ms) old/new effect are similar for faces and words, but the spatial distributions of the late (~600 ms) old/new effect differ. This difference has been taken as evidence that the late old/new effects for faces and words are categorically different, and that these differences are the product of specific attributes of the stimuli or their processing. In other words, the claim is that the neural activity engaged during memory retrieval will vary depending on the type of information (face or verbal material) that is recovered.

While this interpretation is plausible, another interpretation is worth considering. In each of these studies, stimulus type was confounded with whether the stimulus had a pre-existing (long-term) memory representation. The letter strings were words with meaning, but the faces were individuals unknown to the subjects. As such, it is difficult to tease apart whether the ERP effects were in fact driven by categorically different stimuli, or instead by the semantic/long-term memory representations (what we call "stable memory representations") of word stimuli and the absence of such pre-existing, stable memory representations for face stimuli. Evidence for the latter interpretation can be found in the known mnemonic differences between famous and unknown faces. For example, Reder et al. (2013) have found that famous faces are easier to bind to the encoding context than faces of people who are unknown to the subjects. Not only is recognition memory better for faces of known than of unknown people, but this advantage is particularly pronounced in recollection (as opposed to familiarity-based) memory judgments.

In this study, we sought to test the possibility that the observed ERP differences in episodic face recognition arise from differential processing of stimuli with and without a pre-existing representation in LTM. In order to disentangle stimulus type from status of pre-existing memory representations, we compare four stimulus conditions representing the two relevant factors: stimuli (faces vs. letter strings) × LTM representation stability (pre-existing memory representation vs. no pre-existing memory representation). The stimulus materials consisted of faces of celebrities, faces of unknown individuals, common words, and pseudo-words (meaningless pronounceable letter strings). If stimulus type is the critical factor that determines the topography of the late old/new effects, then we would expect to see a parietal late old/new effect for words and letter strings, and a more anterior late old/new effect for famous and unknown faces. Alternatively, if the pre-existing representation in LTM is the critical factor, then we would expect to see a parietal late old/new effect for famous faces and words, and a more anterior late old/new effect for unknown faces and letter strings.

2. Results

2.1. Behavioral results

During the encoding phase, accuracy was above 95% for all stimuli except famous faces (78%), reflecting the fact that subjects did not know all famous faces. Response time (RT) for correct letter strings was faster than for correct faces, $F(1,14)=17.16$, $p<0.001$. Within the letter string category, word RTs were faster than pseudo-words, $F(1,14)=9.21$, $p<0.01$. Within the face category, reaction times were equivalent for famous and unknown individuals ($p>0.05$).

Performance on the episodic memory test that followed encoding is shown in Table 1. Accuracy and RTs for correct judgments are shown as a function of whether the stimulus appeared earlier (old vs. new), whether the stimulus has a pre-existing representation (known vs. unknown), and whether the stimulus is a face or letter string. For completeness, the discrimination index (*Pr*) is also shown for each type of stimulus (Snodgrass and Corwin, 1988). This discrimination index is calculated as the hit rate minus the false alarm rate. Large values denote better performance.

For response accuracy, there were main effects of face vs. letter string, $F(1,14)=70.85$, $p<0.001$, and known vs. unknown, $F(1,14)=53.68$, $p<0.001$. Subjects responded more accurately to faces than to letter strings, and they responded

Table 1 – Accuracy and reaction times (in ms) for correct judgments as a function of whether stimulus is old or new, whether the stimulus has a pre-existing representation, and whether the stimulus is a face or letter string. Pr (discrimination index) for each type of stimuli is also shown. Standard errors are given in parentheses.

	Faces				Words			
	Famous faces		Unknown faces		Words		Pseudo-words	
	Old	New	Old	New	Old	New	Old	New
Acc	0.85(0.03)	0.83(0.02)	0.59(0.04)	0.92(0.03)	0.76(0.05)	0.63(0.05)	0.51(0.06)	0.67(0.06)
Pr	0.68(0.04)		0.51(0.04)		0.30(0.05)		0.18(0.04)	
RTs	798(32)	890(36)	947(39)	798(29)	781(32)	889(36)	881(33)	818(33)

Note: M, mean; Acc, accuracy; RT, reaction time.

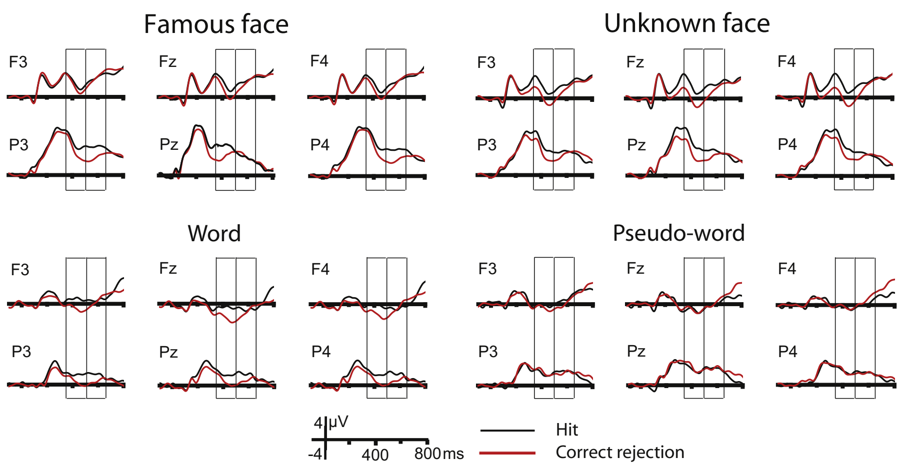

Fig. 1 – Grand average ERP waveforms at representative electrodes for each of the four stimulus types during recognition. Hits (correctly identified old responses) and stimuli correctly identified as new are plotted separately in each graph. The two frames represent the two intervals respectively.

more accurately to items with pre-existing representations than to items without such representations. Finally, there was an interaction between pre-existing representation and target vs. foil (old vs. new) discrimination, $F(1,14)=27.77$, $p<0.001$. The percentage of correctly rejected, unknown items exceeded the percentage of correctly identified, unknown items, $F(1,14)=11.97$, $p<0.01$. For known items, these measures did not differ. The Pr score for faces was more than twice that for words. This is likely because we used medium-to-high frequency words, a point that we return to in the discussion.

For reaction times, there was an interaction between pre-existing representation and target vs. foil discrimination, $F(1,14)=323.33$, $p<0.001$. For unknown items, correct rejections were faster than hits, but for known items, hits were faster than correct rejections. This pattern seems reasonable given that unknown foils had never been seen before and could be rejected purely on the basis of familiarity. For known items, the familiarity difference between targets and foils was not as strong. This finding is mirrored in the ERP results below.

2.2. *ERP results*

ERP analyses were conducted for correct responses. The average number of observations per condition was 29 and no condition averaged fewer than 20 observations per subject. Waveform amplitude analyses focused on frontal and parietal locations as motivated by the literature (e.g., MacKenzie and Donaldson, 2009; Yick and Wilding, 2008). Based on these conventions, we collapsed data from six electrodes to create frontal (F3, Fz, and F4) and parietal (P3, Pz, and P4) regions, and we analyzed ERP data during two latency windows, 350–500 ms (early old/new effect) and 500–650 ms (late old/new effect). We analyzed the data in this manner to directly test for the presence of early and late old/new effects for each of the four stimulus types.

Fig. 1 plots the grand average waveforms for each of the four stimulus types at the 6 analyzed electrodes during episodic recognition. Fig. 2 shows the topographic maps of the old–new effects over the entire scalp for each stimulus type and during the two time intervals of interest. We conducted separate two-way repeated-measures ANOVAs on the mean ERP amplitude during each latency window (350–500 ms and 500–650 ms) and for each of the four stimulus types: famous faces, unknown faces, words, and pseudo-words. Each ANOVA included two factors: old/new (2 levels: hits vs. correct rejections) and site (2 levels: frontal and parietal scalp). Only reliable interactions of old/new and site are reported. Below we present the results by phenomenon of interest.

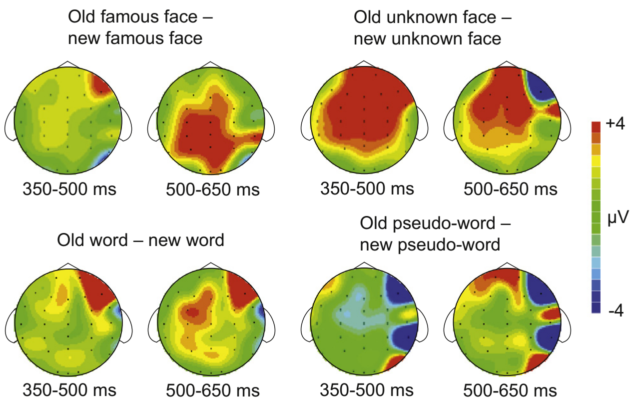

Fig. 2 – Topographic maps of ERP waveforms differences between hits and correct rejections for the four types of stimuli during recognition. Each is shown at the two time intervals of interest.

Table 2 – Mean amplitudes (in μV) of hits minus correct rejections at recognition. The frontal differences are averaged over the F3, FZ, and F4 electrodes, and the parietal differences are averaged over P3, PZ, and P4. Standard errors are given in parentheses.

	Stimuli type	Frontal	Parietal
350–500 ms	Famous faces	1.804 (0.82)	1.796 (0.92)
	Unknown faces	4.681 (0.52)	2.485 (0.26)
	Words	2.534 (1.25)	1.472 (0.70)
	Pseudo-words	0.135 (0.99)	−0.091 (0.79)
500–650 ms	Famous faces	0.874 (1.02)	2.71 (0.88)
	Unknown faces	2.582 (1.06)	0.876 (0.82)
	Words	0.287 (1.16)	1.245 (0.84)
	Pseudo-words	−0.033 (1.33)	0.532 (0.97)

Table 3 – FN400 mean amplitudes (in μV) for famous and unknown faces. Amplitudes are averaged over the F3, FZ, and F4 electrodes. Standard errors are given in parentheses.

	Old	New
Famous faces	4.433 (1.27)	2.629 (1.07)
Unknown faces	4.368 (1.43)	−0.313 (1.28)

2.2.1. *Early old/new effects for famous and unknown faces*

The ANOVA for famous faces from 350 to 500 ms revealed an old/new effect, $F(1,14)=4.94$, $p<0.05$. Waveforms were more positive across frontal and parietal sites for old famous faces than for new famous faces. Unknown faces also produced an early old/new effect, $F(1,14)=131.06$, $p<0.001$. For unknown faces, there was also a reliable interaction between old/new and site, $F(1,14)=16.83$, $p<0.001$, such that the old/new effect was greater at frontal electrodes compared with parietal electrodes.

The size of the early old/new effect was much larger for unknown faces than for famous faces, as confirmed with a follow-up comparison at frontal sites (fame by old/new): the interaction of fame with old/new was reliable, $F(1,14)=11.68$, $p<0.01$, and was driven by the much larger early old/new effect for unknown faces (see Table 2). The smaller old/new effect for famous faces seems reasonable given that foils in the famous face condition still have some familiarity from prior exposure (without which the individuals pictured would not be famous). Support for this interpretation comes from a comparison of the amplitudes of the early old/new effect for correctly rejected faces. In the frontal region, new famous faces were significantly more positive than new unknown faces, $F(1,14)=15.04$, $p<0.01$. The difference in the amplitude of the early old/new effect for famous vs. unknown faces, however, was remarkably small. That is, old famous faces and old unknown faces produced equivalent early responses over the frontal region ($p>0.1$; see Table 3).

2.2.2. *Early old/new effects for words and pseudo-words*

An analogous ANOVA for words also revealed a reliable old/new effect, $F(1,14)=4.99$, $p<0.05$, across frontal and parietal regions (see Table 2). A follow-up comparison with pseudo-words found that the old/new effect was significantly larger for words across sites, $F(1,14)=8.45$, $p<0.05$. In fact, pseudo-words did not show reliable old/new effects in either time window. The absence of effects is consistent with the generally poor accuracy for pseudo-words and may be due to difficulties in encoding. The absence of an early old/new effect is somewhat unusual, however, and a potential explanation is offered in the general discussion.

2.2.3. *Late old/new effects*

MacKenzie and Donaldson (2009) and Yick and Wilding (2008) found a larger late frontal old/new effect for unknown faces, and they found a larger parietal old/new effect for verbal stimuli. For unknown faces at 500–650 ms in our experiment, there was an interaction between old/new and site, $F(1,14)=6.13$, $p<0.05$, such that the old/new effect was larger at the frontal site compared to the parietal site (see Table 2). For words, although the effect was visually apparent (see Figs. 1 and 2), we failed to find a reliable old/new effect at 500–650 ms ($p>0.1$); we suspect that this was because our words were of higher frequency than most related studies. Still, our findings pertaining to unknown faces and words essentially replicate those of earlier studies (MacKenzie and Donaldson, 2009; Yick and Wilding, 2008).

The question of particular interest in this study is whether famous faces behave like words, which share the property of having long-term memory representations, or like unknown faces, which share similar stimulus attributes. If the frontal old/new effect found for unknown faces is material specific, it should also appear for famous faces. It did not. For famous faces, the interaction between old/new and site was significant, $F(1,14)=8.53$, $p<0.05$. Follow-up tests found that during the 500–650 ms time window, famous faces produced a reliable old/new effect at parietal, $F(1,14)=9.55$, $p<0.01$, but not frontal ($p>0.1$), electrodes. In other words, the ERP results for famous faces bear a greater similarity to words' parietal old/new effect than to unknown faces' frontal effect. Indeed, a direct comparison between famous and unknown faces showed a strong interaction between fame, old/new and site, $F(1,14)=21.91$, $p<0.001$, such that famous faces showed old/new differences only at parietal sites, while unknown faces only showed differences at frontal sites. By contrast, the same analysis comparing famous faces to words produced no reliable effects due to the type of material.

3. General discussion

Past studies have investigated the distinct spatial distributions of the late old/new effect of faces and verbal stimuli (e.g., MacKenzie and Donaldson, 2009; Yick and Wilding, 2008), but have not considered that these findings might be based on an attribute of the stimuli other than whether they were faces or verbal stimuli: the faces used as stimuli lack a prior representation in LTM in contrast to the verbal stimuli. The goal of this experiment, then, was to determine to what extent pre-existing memory representations were driving the differences in the late old/new effects of faces and verbal stimuli. In particular, this experiment was set out to answer whether the late frontal old/new effect observed in previous studies that used unknown faces would also appear for famous faces, or whether famous faces would produce an effect more like words and names that also have pre-existing LTM representations.

The present results provide strong evidence for the influence of pre-existing representations in LTM on the electrophysiological data; in contrast to the material specific interpretation, these data show that pre-existing LTM representations modulate late old/new effects. In line with previous studies (e.g., MacKenzie and Donaldson, 2009; Yick and Wilding, 2008), our analyses replicated the scalp distribution patterns of the late old/new effects, showing a qualitatively distinct pattern for unknown faces vs. words, specifically showing an anterior distribution for unknown faces, but a parietal distribution for words. The novel result was that famous faces produced an ERP pattern similar to words but different from unknown faces. The late old/new effect was larger over the parietal regions for famous faces. This pattern suggests that the late old/new effects are modulated by the existence of a stable pre-existing LTM (semantic) representation, and not by the modal attributes of the stimulus.

These data are in line with the perspective that the nature of memory judgments depends upon whether stimuli have previously stored, stable memory representations (Reder et al., 2013). Why might such representations evoke differential processing? First, familiarity may be less diagnostic in determining whether a known item was recently encountered. If a stimulus has a stored representation, by definition it has some inherent familiarity as it has been experienced multiple times in the past. That means that an old/new judgment based on familiarity is less likely to be accurate for previously experienced stimuli such as words and famous faces compared to an unknown stimulus. Second, as we have argued elsewhere (e.g., Reder et al., 2013), stimuli with stable memory representations are more easily encoded and associated with contextual details, thereby making recollection judgments more successful for those types of stimuli. Thus, stable memory representations may impair familiarity-based judgments, while facilitating recollection judgments.

3.1. *Alternative accounts of these findings*

The encoding task in this experiment asked subjects to judge whether or not a face was already known (i.e., famous) and whether or not a letter string was already known (i.e., a word). Conceivably, the observed pattern of results at test might have been caused by the encoding task rather than the stable memory representation, per se. We considered this alternative interpretation before actually conducting the experiment and included a control encoding condition to help rule out that interpretation. We felt it was important to demonstrate that when the encoding task asked for only a face/letter discrimination, the patterns would not reverse, such that the ERP patterns for all faces would be similar to one another but different from all letter strings.

The latter control task is obviously much easier and faster. This type of easy task is often referred to as a "shallow" encoding task (Craik and Lockhart, 1972), and, as such, typically produces weak recollection effects (e.g., Rugg et al., 1998). Previous research has shown that recognition ERPs are sensitive to manipulations of levels of processing at encoding (Sanquist et al., 1980). Despite the poor memory performance in the shallow control task, we were still able to confirm that the pattern of results did not depend on the dimension used to encode the stimuli. Specifically, the pattern of frontal vs. parietal effects for recognized stimuli did not depend on the encoding task, such that all faces showed one ERP pattern and all letter strings another. The details of this condition, including the results, are available in the Supplementary material.

One moderate departure from past studies of the parietal old/new effect that used word stimuli is worth noting: in the current study the late old/new effect for words, though visually apparent, did not reach significance at parietal regions, while prior studies have found larger effects (e.g., MacKenzie and Donaldson, 2009; Yick and Wilding, 2008). A likely explanation for such a difference was that medium-to-high frequency words rather than low frequency words were used in the present experiment. Recollection is more difficult for high than low frequency words (e.g., Reder et al., 2000, 2002), and in ERP studies, high frequency words tend to show reduced old/new effects compared with low frequency words (Rugg et al., 1995).

The present study revealed reliable early old/new effects (including an FN400) for famous faces, unknown faces, and words. In dual-process models, the early old/new effects are often interpreted as familiarity differences between studied and unstudied items (Yonelinas, 2002; Rugg and Curran, 2007). Some evidence suggests that the early old/new effect is sensitive to different aspects of familiarity and that both perceptual and conceptual familiarities may sum up to lead to graded early old/new effect differences (Ecker and Zimmer, 2009). In this light, the graded effect of unknown/new < famous/new < old is quite interesting because it suggests that not only the early old/new effect is sensitive to different aspects of familiarity in the short term, but also that it captures long term (semantic) familiarity in addition to the episodic familiarity that comes from studying the item.

Two additional results, the lack of an early old/new effect for pseudo-words and the early old/new effect for unknown faces, deserve further comment. The absence of an early old/new effect for pseudo-words is inconsistent with the findings of Swick and Knight (1997); however, the retention intervals from study to test in their experiment never exceeded 1 s while our retention intervals ranged from 10 to 20 min. Another study of recognition memory that used nonsense stimuli (Groh-Bordin et al., 2006) recorded a reliable old/new effect; however, their retention intervals (1.3–3.9 min) were still much shorter than the intervals used in our experiment. Thus, we interpret the absence of the early old/new effect for pseudo-words in our study as a consequence of pseudo-words having shorter-lived familiarity traces that faded within the relatively long retention intervals we employed. The low accuracy of our subjects under this condition is consistent with this interpretation.[1]

Unknown faces by contrast did show an early old/new effect, and their very low false alarm rates suggest that familiarity aided subjects in their recognition judgments. Part of this effect may be because, relative to pseudo-words, it is easier to create meaningful associations to unknown faces (e.g., beautiful young blonde).

In fact, the early old/new effect has appeared inconsistently for unknown faces. By comparing multiple studies that directly examine differences between recollection and familiarity for unknown faces (Curran and Hancock, 2007; MacKenzie and Donaldson, 2007; Yovel and Paller, 2004), Donaldson and Curran (2007) suggested that performance, stimulus heterogeneity, and the modality of context information are potential mediators of the FN400. Yick and Wilding (2008) subsequently observed an early old/new effect for unknown faces despite the fact that the performance in their task was somewhat low. Further, they observed an early old/new effect despite the fact that they used fairly homogenous stimuli – black and white photographs of Caucasian faces that had a small range of ages. Consequently, high performance and stimulus heterogeneity now seem less important in obtaining an early old/new effect for unknown faces.

Context remains a plausible mediator of the FN400. Tsivilis et al. (2001) noted that the manner in which context is encoded might result in the absence of the FN400, even when stimuli are familiar. More recently, Ecker et al. (2007) found that when attention was directed toward the stimulus, modifying the context did not significantly attenuate the FN400. When attention was not explicitly directed toward the stimulus, however, modifying the context did attenuate the FN400. Together, these studies suggest that, if context is attended to, familiarity of stimuli alone may not be sufficient to produce an FN400. These considerations notwithstanding the conditions of our task may have been ideal for evoking an early old/new effect for unknown faces: performance for unknown faces was relatively high, stimuli were highly heterogeneous, and context was held constant between the encoding and test phases of the task.

[1]Given the low behavioral accuracy, it is reasonable to wonder whether the accuracy for pseudo-words was unusually poor in the current experiment. However, the performance for unknown stimuli is in line with past studies (e.g., Marzi and Viggiano, 2010).

3.2. *Summary*

The present data suggest that stable pre-existing memory representations mediate the late old/new effect differences previously observed between faces and verbal materials. Across both words and faces, stimuli with stable representations had stronger late old/new effects over the parietal region of the scalp, while stimuli without stable long-term memory representations had stronger late old/new effects over the anterior region of the scalp. In other words, ERP correlates of recollection are modulated by whether stimuli have pre-existing memory representations.

4. Experimental procedures

4.1. *Subjects*

A total of 15 students from Carnegie Mellon University or the University of Pittsburgh (9 males, mean age of 23.6 years) participated in this study. They received payment of $15. All subjects were native English speakers with normal or corrected-to-normal visual acuity, and none reported a history of neurological impairment.

4.2. *Materials*

The experiment consisted of two phases: an encoding task and a subsequent memory test. The experiment used a 2 (stimulus type: faces vs. letter strings) $\times$ 2 (pre-existing memory representation: known vs. unknown) within subject design during the encoding stage, and the test used a simple old/new judgment. There were 384 stimuli, 96 for each of the four types of stimuli: famous faces, unknown faces, words, and pseudo-words. At test, half of the items were targets and half were foils for each stimulus type. Stimuli for each category were randomly assigned to be targets or foils for each subject. All four types of stimuli were randomly intermixed and presentation order of stimuli during both phases was randomized for each subject.

All face stimuli were headshots of adults collected from the Internet. The celebrities were selected on the basis of high fame identification by lab assistants of the same age as prospective subjects. Gender and age distributions were controlled for famous and unknown faces as well as the proportion of "glamour" shots for these faces (glamour photographs were available for unknown faces as well). All image backgrounds were removed using Adobe Photoshop CS4.

All verbal stimuli were four letters in length and did not include homophones. Words included one- and two-syllable concrete nouns such as "boot," "echo," and "navy". Words were chosen using the MRC Psycholinguistic Database (Kučera and Francis, 1967). All words were of moderate-to-high frequency (between 40 and 300 occurrences per million). The majority of the pseudo-words were taken from a previous study (Reder et al., 2002) and the remaining pseudo-words were created using the ARC Nonword Database (Rastle et al., 2002). These letter strings were also one or two syllables, pronounceable, and conformed to English spelling patterns.

4.3. *Procedure*

At the start of the experiment, subjects performed an encoding task. They were told to use their index fingers to press a keyboard key with a sticker label "K" for known faces and for letter strings that were words, and to press a key with a sticker label "U" for unknown faces and for letter strings that were non-words. The actual keys so labeled were F and J. The mapping between labels and response hands was counterbalanced across subjects. Subjects were given several practice trials with feedback to ensure that they understood the task instructions.

After completing the encoding trials, subjects were given a surprise memory test. The memory test consisted of all the stimuli viewed previously plus an equal number of stimuli of each type that had not been judged during the preceding phase. Subjects were instructed that if they remembered classifying the probe during the encoding phase, they were to respond "old" by pressing the key labeled "O". If they did not remember judging the item during the encoding phase, they were told to respond "new" by pressing the key labeled "N". The actual keys so labeled were V and M. The mapping between labels and response hands was counterbalanced across subjects. Subjects were told to respond as quickly and accurately as possible in both the encoding and the test stages. A schematic illustration of the procedure is shown in Fig. 3.

The trial structure was the same for the encoding and test phases of the experiment. At the start of each trial, a fixation cross appeared at the center of the monitor for 1000 ms, and was followed by an image. Images were displayed centrally against a gray background on a Dell Dimension 8200 monitor, and were followed by a blank screen. The presentation time for each item was determined by the duration of a subject's response time with the constraint that no trial lasted more than 2 s for either phase of the experiment. The total duration of each item and the following inter-trial interval was always 3 s, regardless of whether the key press was correct, incorrect, or missing.

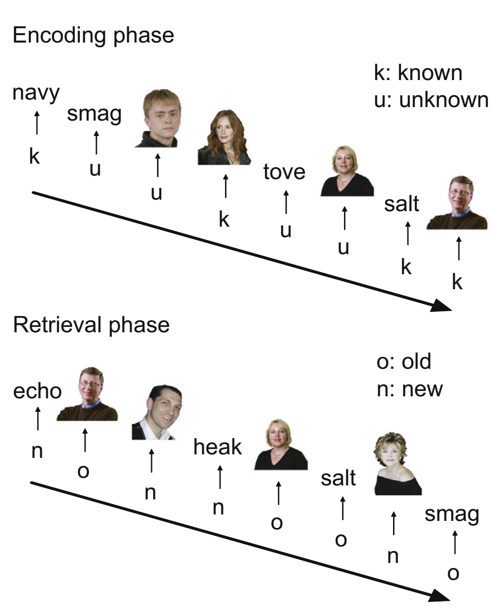

Fig. 3 – Schematic illustration of the experimental procedure.

The computer screen was placed 70 cm from subjects. Visual angles subtended by face stimuli were 2.5° (horizontal) and 3.9° (vertical), and the vertical visual angle subtended by each letter string was 0.64°. Words and pseudo-words were presented in black, lowercase Courier New Font. Subjects were instructed to fixate on the center of the screen, and they were instructed to minimize eye blinks while stimuli were on the screen.

4.4. *Electrophysiological recording*

Subjects sat in an electrically shielded booth during the experiment. The EEG was recorded continuously with Synamp amplifiers from 32 Ag/AgCl electrodes (10–20 system). The vertical EOG was recorded from electrodes placed on the supra- and infra-orbital ridges of the left eye, and the horizontal EOG was recorded from electrodes placed at the external canthi of both eyes. The right mastoid served as the reference electrode, and scalp recordings were algebraically re-referenced offline to the average of the right and left mastoids. All signals were amplified with a gain of 250 and were digitized at a sampling rate of 250 Hz, and were filtered with a band-pass of 0.05–70 Hz. Electrode impedances were kept below 5 kΩ.

Eye artifact correction was accomplished using a semi-automatic procedure before averaging (Nie et al., 2013; Picton et al., 2000). Following correction, any additional trials contaminated by movements exceeding $\pm 100\ \mu V$ were excluded before collapsing using a PCA-based algorithm (Nowagk and Pfeifer, 1996). Epochs of 900 ms (including a 100 ms baseline) were then extracted from the continuous recording and corrected over the pre-stimulus interval. For the test phase of the experiment, grand-average waveforms were created for hits and correct rejections for the four types of stimuli (famous and unknown individuals, and words and pseudo-words).

Acknowledgments

We wish to thank V. Quinlan for help with data collection and A. Manelis for comments on the manuscript. Author AN was supported by the following Chinese funding sources: NSFC (31300831), NSF (Y12C090015) and SSF (11JCJY01YB and 13ZJQN036YB) of Zhejiang Province. Authors AK and AD were supported by NIH training grant R90DA023426 and MW by NIH training grant T32MH019983. The research was supported by LR's NIMH grant 5R01MH052808.

Appendix A. Supplementary material

Supplementary data associated with this article can be found in the online version at http://dx.doi.org/10.1016/j.brainres.2014.02.010.

REFERENCES

Craik, F.I.M., Lockhart, R.S., 1972. Levels of processing: a framework for memory research. J. Verbal Learn. Verbal Behav. 11, 671–684.

Curran, T., 1999. The electrophysiology of incidental and intentional retrieval: ERP old/new effects in lexical decision and recognition memory. Neuropsychologia 37, 660–674.

Curran, T., Doyle, J., 2011. Picture superiority doubly dissociates the ERP correlates of recollection and familiarity. J. Cogn. Neurosci. 23 (5), 1247–1262.

Curran, T., Hancock, J., 2007. The FN400 indexes familiarity-based recognition of faces. NeuroImage 36, 464–471.

Diana, R., Vilberg, K.L., Reder, L.M., 2005. Identifying the ERP correlate of a recognition memory search attempt. Cogn. Brain Res. 24, 674–684.

Donaldson, D.I., Curran, T., 2007. Potential (ERP) studies of recognition memory for faces. NeuroImage 36, 488–489.

Ecker, U.K., Zimmer, H.D., 2009. ERP evidence for flexible adjustment of retrieval orientation and its influence on familiarity. J. Cogn. Neurosci. 21 (10), 1907–1919.

Ecker, U.K., Zimmer, H.D., Groh-Bordin, C., Mecklinger, A., 2007. Context effectcs on familiarity are familiarity effects of context – an electrophysiological study. Int. J. Psychophysiol. 64, 146–156.

Graham, R., Cabeza, R., 2001. Dissociating the neural correlates of item and context memory: an ERP study of face recognition. Can. J. Exp. Psychol. 55, 154–161.

Groh-Bordin, C., Zimmer, H.D., Ecker, U.K., 2006. Has the butcher on the bus dyed his hair? When color changes modulate ERP correlates of familiarity and recollection. NeuroImage 32, 1879–1890.

Jacoby, L.L., 1991. A process dissociation framework: separating automatic from intentional uses of memory. J. Mem. Lang. 30, 513–541.

Kučera, H., Francis, W.N., 1967. In: Computational Analysis of Present Day American English. Brown University Press, Providence, RI.

MacKenzie, G., Donaldson, D.I., 2007. Dissociating recollection from familiarity: electrophysiological evidence that familiarity for faces is associated with a posterior old-new effect. Neuroimage 36, 454–463.

MacKenzie, G., Donaldson, D.I., 2009. Examining the neural basis of episodic memory: ERP evidence that faces are recollected differently from names. Neuropsychologia, 47; 2756–2765.

Marzi, T., Viggiano, M.P., 2010. Deep and shallow encoding effects on face recognition: an ERP study. Int. J. Psychophysiol. 78, 239–250.

Nie, A.Q., Guo, C.Y., Liang, J.Y., Shen, M.W., 2013. The effect of late posterior negativity in retrieving the color of Chinese characters. Neurosci. Lett. 534, 223–227.

Nowagk, R., Pfeifer, E., 1996. Unix implementation of the ERP evaluation package. Max Planck Institute of Cognitive Neuroscience124–126 (Annual Report 1996).

Paller, K.A., Gonsalves, B., Grabowecky, M., Bozic, V.S., Yamada, S., 2000. Electrophysiological correlates of recollecting faces of known and unknown individuals. NeuroImage 11, 98–110.

Picton, T.W., Bentin, S., Berg, P., Donchin, E., Hillyard, S.A., Johnson, R.J.R., Miller, G.A., Ritter, W., Ruchkin, D.S., Rugg, M. D., Taylor, M.J., 2000. Guidelines for using human event-related potentials to study cognition: Recording standards and publication criteria. Psychophysiology 37, 127–152.

Rastle, K., Harrington, J., Coltheart, M., 2002. 358, 534 nonwords: the ARC nonword database. Q. J. Exp. Psychol. A 55 (4), 1339–1362.

Reder, L.M., Angstadt, P., Cary, M., Erickson, M.A., Ayers, M.S., 2002. A reexamination of stimulus-frequency effects in recognition: two mirrors for low- and high-frequency pseudowords. J. Exp. Psychol. Learn. 28 (1), 138–152.

Reder, L.M., Nhouyvanisvong, A., Schunn, C.D., Ayers, M.S., Angstadt, P., Hiraki, K., 2000. A mechanistic account of the mirror effect for word frequency: a computational model of remember–know judgments in a continuous recognition paradigm. J. Exp. Psychol. Learn. 26 (2), 294–320.

Reder, L.M., Victoria, L.W., Manelis, A., Oates, J.M., Dutcher, J.M., Bates, J.T., Cook, S., Aizenstein, H.A., Quinlan, J., Gyulai, F., 2013. Why it's easier to remember seeing a face we already know than one we don't: pre-existing memory representations facilitate memory formation. Psychol. Sci. 24 (3), 363–372.

Rugg, M.D., Cox, C.J.C., Doyle, M.C., 1995. Event-related potentials and the recollection of low and high frequency words. Neuropsychologia 33 (4), 471–484.

Rugg, M.D., Curran, T., 2007. Event-related potentials and recognition memory. Trends Cogn. Sci. 11 (5), 251–257.

Rugg, M.D., Mark, R.E., Walla, P., Schloerscheidt, A.M., Birch, C.S., Allan, K., 1998. Dissociation of the neural correlates of implicit and explicit memory. Nature 392, 595–598.

Sanquist, T.F., Rohrbaugh, J.W., Syndulko, K., 1980. Electrocortical signs of levels of processing: Perceptual analysis and recognition memory. Psychophysiology 17 (6), 568–576.

Snodgrass, J.G., Corwin, J., 1988. Pragmatics of measuring recognition memory: Applications to dementia and amnesia. J. Exp. Psychol. Gen. 117 (1), 34–50.

Swick, D., Knight, R.T., 1997. Event-related potentials differentiate the effects of aging on word and nonword repetition in explicit and implicit memory tasks. J. Exp. Psychol. Learn. 23 (1), 123–142.

Tsivilis, D., Otten, L.J., Rugg, M.D., 2001. Context effects on the neural correlates of recognition memory: An electrophysiological study. Neuron 31, 497–505.

Wilding, E.L., Doyle, M.C., Rugg, M.D., 1995. Recognition memory with and without retrieval of context: An event-related potential study. Neuropsychologia 33 (6), 743–767.

Yick, Y., Wilding, E.L., 2008. Material-specific neural correlates of memory retrieval. NeuroReport 19 (158), 1463–1467.

Yonelinas, A.P., 2002. The nature of recollection and familiarity: a review of 30 years of research. J. Mem. Lang. 46, 441–517.

Yovel, G., Paller, K.A., 2004. The neural basis of the butcher-on-the-bus phenomenon: when a face seems familiar but is not remembered. Neuroimage 21, 789–800.